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Wilma L. Zijlema

Ania Stasinska

David Blake
Edith Cowan University, d.blake@ecu.edu.au

Mila Dirgawati

Leon Flicker

See next page for additional authors

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The longitudinal association between natural outdoor environments and mortality in 9218 older men from Perth, Western Australia

Wilma L. Zijlema[a,b,c,*], Ania Stasinska[d], David Blake[e], Mila Dirgawati[d], Leon Flicker[f], Bu B. Yeap[g], Jonathan Golledge[h], Graeme J. Hankey[i], Mark Nieuwenhuijsen[a,b,c], Jane Heyworth[d]

[a] Barcelona Institute for Global Health (ISGlobal), Barcelona, Catalonia, Spain
[b] Universitat Pompeu Fabra (UPF), Barcelona, Catalonia, Spain
[c] CIBER Epidemiología y Salud Pública (CIBERESP), Barcelona, Catalonia, Spain
[d] School of Population and Global Health, The University of Western Australia, Perth, Western Australia, Australia
[e] Centre for Ecosystem Management, School of Science, Edith Cowan University, Joondalup, Western Australia, Australia
[f] Western Australian Centre for Health & Ageing, Centre for Medical Research, The University of Western Australia, Perth, Western Australia, Australia
[g] Medical School, University of Western Australia, Department of Endocrinology and Diabetes, Fiona Stanley Hospital, Perth, Western Australia, Australia
[h] Queensland Research Centre for Peripheral Vascular Disease, College of Medicine and Dentistry, James Cook University, Department of Vascular and Endovascular Surgery, The Townsville Hospital, Townsville, Queensland, Australia
[i] Medical School, The University of Western Australia, Department of Neurology, Sir Charles Gairdner Hospital, Perth, Western Australia, Australia

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ABSTRACT

Background/Aim: Natural outdoor environments may mitigate harmful environmental factors associated with city living. We studied the longitudinal relationship between natural ('green and blue') outdoor environments and mortality in a cohort of older men residing in Perth, Western Australia.
Methods: We studied a cohort of 9218 men aged 65 years and older from the Health In Men Study. Participants were recruited in 1996–99 and followed until 2014, during which 5889 deaths were observed. Time-varying residential surrounding greenness based on the Normalized Difference Vegetation Index, and the number and size of parks, natural space and waterbodies were defined to characterize the natural outdoor environment. All-cause non-accidental and cause-specific mortality was ascertained with the Western Australian Data Linkage System. The association of the natural outdoor environment with mortality was examined using Cox regression analysis.
Results: After adjusting for age, men living in the highest quartile of cumulative average surrounding greenness had a 9% lower rate of all-cause non-accidental mortality (95% confidence interval [CI] 0.84, 0.98; p = .013) compared with those in the lowest quartile. This association was no longer present after adjustment for other risk factors, especially level of education. Living within 500 m of one (vs. no) natural space was associated with decreased mortality risk (adjusted hazard ratio 0.93; 95% CI 0.86, 1.00; p = .046), but no association with mortality was found for two or more natural spaces compared to none and for parks. Associations between waterbodies and mortality were inconsistent, showing non-linear beneficial and harmful associations.
Conclusions: In this longitudinal study of older men residing in Perth, we observed evidence suggestive of an association between access to natural spaces and decreased mortality. Associations between surrounding greenness and mortality seemed to be confounded by level of education, and associations with waterbodies were complex and need to be studied further.

1. Introduction

Globally, the growth of urban areas and the influx of people into urban areas has resulted in a major shift towards more people living in cities than in rural areas. For the coming years it is expected that even a larger part of the world's population will live in cities (United Nations, 2018). There may be some health advantages of living in the cities, such as more ready access to specialist health care, but there may also be disadvantages, such as increased pollution and reduced availability of outdoor areas to exercise (Rydin et al., 2012). One way of promoting

* Corresponding author at: Barcelona Institute for Global Health (ISGlobal), Barcelona Biomedical Research Park (PRBB), C/Doctor Aiguader 88, 08003 Barcelona, Spain.
E-mail address: wilma.zijlema@isglobal.org (W.L. Zijlema).

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health of urban residents may lie in the introduction of urban natural outdoor environments, such as parks, street trees, and urban gardens (Frumkin et al., 2017; Giles-Corti et al., 2016; Nieuwenhuijsen et al., 2017). Such natural outdoor environments may promote physical activity (Bancroft et al., 2015) and neighborhood social cohesion (Kuo et al., 1998). They may simultaneously protect against harmful environmental exposures by improving air quality (Dadvand et al., 2012), reducing noise (annoyance) (Dzhambov et al., 2018; Dzhambov and Dimitrova, 2014), and by reducing urban heat island effects (Burkart et al., 2015). They may further serve as a buffer for stress and offer a place for mental restoration (Bratman et al., 2012). It is thought that through these pathways, natural outdoor environments have the potential to benefit both mental and physical health (Markevych et al., 2017).

A variety of health benefits related to natural outdoor environments (NOE) have been reported. A meta-analysis reported a 8% reduction in all-cause mortality and 4% reduction in cardiovascular mortality for residents with the highest NOE exposure compared with the lowest exposure group (Gascon et al., 2016). Two other studies observed similar relationships and found that residential surrounding greenness and visits to green spaces were related to reductions in all-cause mortality (James et al., 2016; Sulander et al., 2016). Moreover, exposure to NOE might have the ability to decrease health inequalities related to socioeconomic differences (Mitchell and Popham, 2008).

Associations between NOE and disease-specific mortality may provide insight into potential pathways. Most consistent associations have been reported between residential NOE and decreased risks of cardiovascular mortality (Gascon et al., 2016). Decreased risks of respiratory disease related mortality have also been reported (James et al., 2016; Richardson and Mitchell, 2010; Villeneuve et al., 2012).

The current evidence seems suggestive for a beneficial effect of NOE on health, but a number of questions remain (Gascon et al., 2016). First, some studies have reported inconsistent findings. For example, an ecological study reported higher mortality in greener US cities (Richardson et al., 2012); lower mortality risks were observed in greener areas for men, but not women in an ecological study in the UK (Richardson and Mitchell, 2010); and a small area study from Spain reported increased mortality risk in areas with higher surrounding greenness (de Keijzer et al., 2016), indicating that further studies are needed to strengthen the evidence base. Second, most of the current evidence is based on cross-sectional or ecological studies, and reverse causation may be important. Longitudinal studies, that clarify the temporal relationships and the long-term associations between natural environments and mortality, are needed. Third, most focus on greenness, but health benefits are also being attributed to other natural outdoor spaces such as waterbodies ('blue spaces' e.g. lakes, rivers, sea) (Burkart et al., 2015; Gascon et al., 2017). Relationships between blue spaces and mortality have been assessed by one previous Canadian study (Crouse et al., 2018), and by two studies that evaluated effect modification of temperature-related mortality by waterbodies (Burkart et al., 2015; Madrigano et al., 2013), and should be explored further.

We studied the longitudinal association between natural outdoor environments (surrounding greenness, parks, natural space, waterbodies) and all-cause and cause-specific mortality in a cohort of older men residing in Perth, Western Australia.

2. Methods

2.1. Study design and participants

This study was based on data from the Health In Men Study (HIMS), which is a community-based cohort of older men living in Perth, Western Australia (Norman et al., 2009). Perth is the capital of Western Australia and is situated on the Indian Ocean coast. It has a hot-summer Mediterranean climate and had 2 million inhabitants in the metropolitan area in 2014. Briefly, participants were originally recruited in 1996–1999 for a population-based randomized control trial of screening for abdominal aortic aneurysms. For that trial, men aged 65 years and older were identified from the electoral roll and 19,352 men were invited to participate. Sixty- 3% (12,203) agreed and completed baseline screening. Follow up measurements were conducted in 2001–2004 (5590 of the 10,940 surviving participants responded) and in 2008 (3202 of the 7200 surviving participants responded) (Norman et al., 2009). Further follow up of outcomes in all men up to December 2014 was undertaken by linkage to the Western Australian Data Linkage System (http://www.datalinkage-wa.org.au). Of the 12,203 participants, those without a geocoded address or who changed address during the study period (years 1996–2014; $n = 2955$), and those who died as a result of an accidental cause ($n = 23$) were excluded from our sample. Another $n = 7$ participants were excluded because of missing data, resulting in sample of 9218 participants included in the current study. All men provided written informed consent to participate and the study protocol was approved by the Human Research Ethics Committee of The University of Western Australia.

2.2. Mortality data

Information on all-cause and cause-specific mortality was obtained from the Western Australia Data Linkage System, which combines databases with records on all inpatient hospital admissions, births, cancers, public sector mental health services, and deaths in Western Australia. Linkage to the HIMS is undertaken every 6–12 months, with the most recent update that includes coding for causes of mortality on 31 December 2014. Date of death and cause of death according to the International Classification of Diseases 9th and 10th Revision (ICD-9 and ICD-10) were obtained from death certificates. We analyzed deaths from all non-accidental causes (primary outcome), and cause-specific deaths including cardiovascular disease (ICD-9 codes: 390-429; 440-448 ICD-10 codes: I00-I59; I70-I78); stroke (ICD-9 codes: 430-438 ICD-10 codes: I60-I69); respiratory diseases (ICD-9 codes: 460-519 IDC-10 codes: J00-J99) and cancer (ICD-9 codes: 140-208; ICD-10 codes: C00-C97).

2.3. Assessment of the natural outdoor environment

Participants' home addresses were geocoded and indicators of the NOE were assigned using a geographic information system. NOE were assessed within buffers around the residence or as distance to nearest NOE. Various buffer sizes were used, where small buffers (100–300 m) refer to the immediate neighborhood NOE, and larger buffers (500–1000 m) refer to NOE that people can visit for specific recreational purposes (Smith et al., 2017). More specifically, the 100 m buffer captures the immediate neighborhood NOE; the 300 m buffer is a commonly used accessibility threshold and World Health Organization standard (Annerstedt van den Bosch et al., 2016); and the 500 and 1000 m buffers refer to 5–10 min walking distances (Smith et al., 2017). The buffer sizes were not necessarily the same for each NOE indicator but depended on the hypothesized mechanism and data variability (see below). NOE indicators were recoded into categories based on the distribution of data to ensure sufficient sample size in each category.

2.4. Residential surrounding greenness

This was estimated with the Normalized Difference Vegetation Index (NDVI) which is a commonly used indicator of vegetation in epidemiological studies (Gascon et al., 2016; James et al., 2015). The NDVI captures the level of photosynthetic activity in a certain area and is derived from satellite images. The NDVI is based on the fact that healthy vegetation absorbs most visible light and reflects large parts of near-infrared light, while sparse vegetation reflects more visible light and less near-infrared light. Based on this distinction, a value between −1.0 and +1.0 is calculated, with higher values indicating higher density of green vegetation (Weier and Herring, 2000). In the current study images were available from Landsat 7 ETM at a resolution of 30 m × 30 m. Cloud-free images within the greenest season (June–October) were obtained for periods 1997, 2002, 2007, and 2012. Waterbodies were excluded from the images since waterbodies have very low NDVI values (Nieuwenhuijsen et al., 2018; Triguero-Mas et al., 2015). The average NDVI value within buffers of 100, 300 and 500 m were determined for all residences of HIMS participants.

2.5. Parks and natural spaces

Number and size of parks and natural spaces were obtained from the Public Open Space (POS) dataset for the Perth and Peel metropolitan region (Francis et al., 2012; Sugiyama et al., 2010). POS are spaces reserved for the provision of green space and natural environments that are freely accessible and intended for recreational purposes by the general public (www.postool.com.au). POS are classified into different types; two of these were used in this study: parks; nature and bushland. The total number of POS was recorded within 500 m circular (Euclidian) and road network buffers, and POS area size in 1000 m circular (Euclidian) and road network buffers around the participant's residence in order to maximize variability. The entire POS area falling within the specified buffer was recorded, even if a part of the POS area falls outside the specified buffer. POS data that were used were available for time period of 2011–2012. Road network data for the road network buffers were available from Main Roads Western Australia for year 2012. We included walkable roads (e.g. main and minor roads, laneways) but excluded freeways which are strictly traffic only. Although the time period applicable to these data was not overlapping with the entire study period, it was assumed that the POS availability was stable over time.

2.6. Waterbodies

Proximity to, number and size of waterbodies (including lakes, rivers and the ocean) was determined by identifying above-ground rivers and lakes across the Perth metropolitan area within 500 m and 1000 m circular (Euclidian) buffers around the participant's residence. The straight-line distance from the participant's residence to the nearest waterbody was recorded as a measure of proximity to waterbodies. Furthermore, the number and total area size of waterbodies within the buffers were determined. Only waterbodies with a minimum size of 2500 m^2 were included. Waterbodies were identified from the land use map Landgate and published for year 2014. Although the time period applicable to these data was not overlapping with the entire study period, it was assumed that the waterbody availability was stable over time.

2.7. Covariates

Identification of potential confounders was based on previous research (Gascon et al., 2016; James et al., 2016; Villeneuve et al., 2012). Information on age (years), marital status (never married; married or de facto; separated or divorced; widowed), country of birth (Australia; Northern Europe, Mediterranean, other), highest obtained educational degree (primary school or never attended school; some high school; high school; university or other tertiary education), and smoking status (never; former; current) was obtained at baseline by questionnaires. Area-level socio-economic status (SES) was categorized based upon the Australian Bureau of Statistics Index of Relative Socio-economic Advantage and Disadvantage 2011. The index includes information on economic and social conditions of people and households within each postal code area in Australia, with low scores indicating a relative greater disadvantage and high scores indicating a relative greater advantage in general (Australian Bureau of Statistics, 2013). For each HIMS participant, the score was based on the postal code area of their baseline residence and participants' scores were subsequently categorized into quintiles of area-level SES.

2.8. Statistical analyses

We used time-varying Cox proportional hazards analyses for estimation of hazard ratios (HRs) and 95% confidence intervals (CIs) for associations between residential surrounding greenness (NDVI) and mortality outcomes. Cox proportional hazards analyses (not time-varying) were used to estimate associations between the parks, natural space, and waterbodies exposures measures and mortality outcomes. Survival time was defined from date of baseline measurement until the date of death or end of follow up (31 December 2014), whichever came first. Models were firstly adjusted for age, and additionally for marital status, country of birth, education level, area-level socioeconomic status, and smoking status. Analyses with residential surrounding greenness were also stepwise adjusted for the covariates and the relative change of HRs was calculated in order to investigative confounding: $(HR_{adjusted} - HR_{unadjusted}) / HR_{unadjusted} * 100$. Stratified analyses for residential surrounding greenness and all-cause mortality were undertaken in strata of area SES (disadvantaged: quintile 1–2; and advantaged: quintile 3–5) to investigate effect modification. Finally, analyses with residential surrounding greenness (500 m buffer) and all-cause mortality were additionally adjusted for waterbody number and size (500 m buffers) to investigate potential confounding. The assumption of proportional hazards was assessed visually with Kaplan-Meier plots. Data were analyzed using STATA 14.2.

3. Results

At baseline, participants were on average 72.2 (standard deviation [SD] 4.41) years of age, and most were married (82.5%), attended some high school (37%), and only 10.4% were current smokers (Table 1). The baseline average surrounding greenness was 0.35 (SD 0.06), and participants had on average 3.94 (SD 2.17) parks and 0.71 natural spaces (SD 1.16) within 500 m of their residence. The mean distance to the nearest waterbody was 676 m (SD 438 m), and the average number of waterbodies within 500 m was 0.57 (SD 0.92) (Table 1).

3.1. Residential surrounding greenness and mortality

We observed 5892 deaths over 111,448 person-years of follow up among 9218 participants. Age-adjusted analyses suggested a reduced mortality risk among those with higher surrounding greenness. For example, those living in the highest quartile of cumulative average greenness within 300 m buffers had a 9% lower hazard of all-cause mortality (95% confidence interval [CI] 0.84, 0.98) than those in the lowest quartile. However, in the fully adjusted models, the association between surrounding greenness and mortality attenuated and was no longer statistically significant (HR 0.97, 95% CI 0.89, 1.05). Results were similar for the 100 m and 500 m buffers (Table 2). Stepwise adjustment of the models showed that adjustment for level of education resulted in the largest relative increase of HRs (2.74 to 3.78%; Supplemental Material, Table S1). Analyses stratified by area SES showed no clear pattern of effect modification (Supplemental Material, Table S2). Associations between residential surrounding greenness and mortality remained similar after additional adjustment for number and size of waterbodies (Supplemental Material, Table S3).

3.2. Parks, natural spaces and mortality

While there were no associations between the number and size of parks and all-cause mortality (Table 3), the number and area size of natural space were associated with lower mortality rates within 500 m (circular and road network), and 1000 m (circular) buffers in the age-adjusted analyses. In the fully adjusted models, only the association

Table 1
Characteristics of the Health In Men Study participants at baseline, Perth Western Australia (*n* = 9218).

Characteristic	Total n = 9218
Deaths, n (%)	5889 (63.9)
Median survival, days (IQR)	13.7 (9.27)
Years of age, mean (± SD)	72.2 (± 4.41)
Marital status, n (%)	
Never married	370 (4.01)
Now married (or de facto)	7613 (82.5)
Separated or divorced	556 (6.03)
Widowed	684 (7.43)
Highest level of education, n (%)	
Primary school or Never attended school	2189 (23.7)
Some high school	3413 (37.0)
Completed high school (year 12 or equivalent)	2164 (23.5)
Completed university or other tertiary degree	1454 (15.8)
Area level (dis)advantage, n (%)	
1 most disadvantaged	1939 (21.0)
2	1829 (19.6)
3	1802 (19.6)
4	1804 (19.6)
5 most advantaged	1840 (20.0)
Smoking status, n (%)	
Current	956 (10.4)
Former	5517 (59.8)
Never	2752 (29.8)
Place of birth, n (%)	
Australia	5050 (57.7)
Northern Europe	2492 (27.0)
Mediterranean	1009 (10.9)
Other	674 (7.31)
Residential surrounding greenness within 100 m, mean (SD)	0.35 (± 0.06)
Residential surrounding greenness within 300 m, mean (SD)	0.35 (± 0.05)
Residential surrounding greenness within 500 m, mean (SD)	0.35 (± 0.05)
Number of parks within 500 m circular/road network buffer, mean (SD)	3.94 (± 2.17)/1.96 (± 1.31)
Size of parks within 1000 m circular/road network buffer (hectare), mean (SD)	30.6 (± 21.9)/16.6 (± 16.2)
Number of natural spaces within 500 m circular/ road network buffer, mean (SD)	0.71 (± 1.16)/0.33 (± 0.69)
Size of natural spaces within 1000 m circular/ road network buffer(hectare), mean (SD)	109.5 (± 711.0)/48.9 (± 394.9)
Distance to nearest waterbody (m), mean (SD)	676 (± 438)
Number of waterbodies within 500 m, mean (SD)	0.57 (± 0.92)
Number of waterbodies within 1000 m, mean (SD)	2.16 (± 2.31)
Size of waterbodies within 500 m (hectare), mean (SD)	1.66 (± 5.03)
Size of waterbodies within 1000 m (hectare), mean (SD)	14.4 (± 28.2)

Note: IQR, interquartile range; SD, standard deviation.

between the number of natural spaces in 500 m road network buffer and mortality remained statistically significant (one natural space vs. no natural space: HR 0.93, 95% CI 0.86; 1.00; Table 4).

3.3. Waterbodies and mortality

There was some indication for a higher all-cause mortality rate in men living further away from the nearest waterbody, than those living closest to water, but only for quartile 2 vs. quartile 1: fully adjusted HR 1.10 (95% CI 1.02; 1.18), and not for the other quartiles (Table 5). The fully adjusted associations between the number of waterbodies and mortality were mostly non-significant, with one exception: there was a 7% higher mortality rate (95% CI 1.00; 1.15) in men living in areas with two or more waterbodies within 1000 m than in those without waterbodies. Furthermore, there was an increased hazard of mortality for those with intermediate waterbody size in the 500 m buffer compared to smallest size (adjusted HR 1.16, 95% CI 1.04; 1.30) (Table 6).

Table 2
Hazard ratios and 95% confidence intervals for residential surrounding greenness and all-cause mortality in the Health In Men Study (n = 9218 with 5889 deaths).

Time varying exposure	Deaths n	Age adjusted HR (95% CI)	Fully adjusted HR (95% CI)
Residential surrounding greenness within 100 m			
Quartile 1	1506	Reference	Reference
Quartile 2	1531	0.99 (0.92, 1.06)	0.99 (0.93, 1.07)
Quartile 3	1503	0.99 (0.92, 1.06)	1.02 (0.95, 1.09)
Quartile 4	1349	0.92 (0.86, 1.00)*	0.97 (0.90, 1.05)
Residential surrounding greenness within 300 m			
Quartile 1	1537	Reference	Reference
Quartile 2	1580	1.03 (0.96, 1.11)	1.04 (0.97, 1.12)
Quartile 3	1446	0.96 (0.90, 1.04)	0.99 (0.92, 1.06)
Quartile 4	1326	0.91 (0.84, 0.98)*	0.97 (0.89, 1.05)
Residential surrounding greenness within 500 m			
Quartile 1	1566	Reference	Reference
Quartile 2	1561	1.01 (0.94, 1.08)	1.02 (0.95, 1.09)
Quartile 3	1456	0.95 (0.88, 1.02)	0.98 (0.91, 1.05)
Quartile 4	1306	0.90 (0.83, 0.97)*	0.96 (0.89, 1.04)

Note: HR, hazard ratio; 95% CI, 95% confidence interval. Fully adjusted models included age, marital status, country of birth, education level, area-level socioeconomic status, and smoking status. * $p < .05$.

3.4. Cause-specific mortality

Cause-specific mortality analyses showed that residential surrounding greenness was associated with a lower hazard of mortality related to respiratory disease in age adjusted analyses, but associations were no longer statistically significant in the fully adjusted models (Supplemental Material, Table S4). In the fully adjusted models, there were lower stroke mortality rates related to the number and size of natural spaces, but not for parks (Supplemental Material, Table S5–6). Finally, an increased hazard of cardiovascular disease mortality for those with intermediate waterbody size (500 m buffer) compared to smallest size was observed in the fully adjusted model. No other associations between cause-specific mortality and waterbody exposure indicators were observed (Supplemental Material, Table S7–8).

4. Discussion

In this study of 9218 elderly men living in Perth, Western Australia, we found that men with a higher level of residential surrounding greenness had a lower mortality risk compared with those with less greenness, but these associations appeared to be confounded by education level. Living in the vicinity of a natural area was associated with decreased mortality. Although closer residential proximity to waterbodies seemed to be related to a lower mortality risk, a higher number of waterbodies was related to a higher mortality risk. Analyses with different strata of neighborhood SES, with both surrounding greenness and number and size of waterbodies, and for cause-specific mortality did not show a consistent pattern of reduced mortality risk.

Previous studies using the NDVI showed associations between higher levels of greenness and decreased mortality while adjusting for confounders. An 8-year prospective US based study in 108,630 female nurses showed that higher levels of vegetation assessed with the NDVI were associated with lower all-cause mortality risk, and specifically with lower respiratory and cancer related mortality (James et al., 2016). A study in Ontario, Canada that followed 575,000 adults for 22 years, reported that individuals with more greenness had lower mortality rates, including, cardiopulmonary, cardiovascular disease,

Table 3
Hazard ratios and 95% confidence intervals for number and size of parks and all-cause mortality in the Health In Men Study (n = 9218 with 5889 deaths).

	Circular buffer			Road network buffer		
Parks	Deaths n	Age adjusted HR (95% CI)	Fully adjusted HR (95% CI)	Deaths n	Age adjusted HR (95% CI)	Fully adjusted HR (95% CI)
Number (500 m buffer)						
0	188	Reference	Reference	516	Reference	Reference
1	503	0.99 (0.83, 1.17)	1.00 (0.84, 1.18)	1728	1.00 (0.91, 1.10)	0.99 (0.89, 1.09)
≥ 2	5201	1.03 (0.89, 1.19)	1.01 (0.87, 1.16)	3648	1.05 (0.96, 1.15)	1.03 (0.94, 1.13)
Size (1000 m buffer[a])						
Tertile 1	1998	Reference	Reference	1895	Reference	Reference
Tertile 2	1905	0.98 (0.92, 1.05)	1.02 (0.96, 1.08)	1961	0.99 (0.93, 1.05)	1.01 (0.95, 1.08)
Tertile 3	1985	1.00 (0.94, 1.07)	1.03 (0.97, 1.10)	2023	1.02 (0.96, 1.08)	1.05 (0.98, 1.12)

Note: HR, hazard ratio; 95% CI, 95% confidence interval. Fully adjusted models included age, marital status, country of birth, education level, area-level socioeconomic status, and smoking status.
[a] Sample size differs due to missing data for park area.

Table 4
Hazard ratios and 95% confidence intervals for number and size of natural space and all-cause mortality in the Health In Men Study (n = 9218 with 5889 deaths).

	Circular buffer			Road network buffer		
Natural spaces	Deaths n	Age adjusted HR (95% CI)	Fully adjusted HR (95% CI)	Deaths n	Age adjusted HR (95% CI)	Fully adjusted HR (95% CI)
Number (500 m buffer)						
0	3628	Reference	Reference	4232	Reference	Reference
1	1241	0.93 (0.87, 1.00)*	0.96 (0.90, 1.02)	913	0.90 (0.84, 0.97)*	0.93 (0.86, 1.00)*
≥ 2	1023	0.97 (0.90, 1.04)	0.97 (0.90, 1.04)	747	0.97 (0.90, 1.05)	0.97 (0.90, 1.05)
Size (1000 m buffer[a])						
Tertile 1	2030	Reference	Reference	1895	Reference	Reference
Tertile 2	1925	0.92 (0.86, 0.98)*	0.96 (0.90, 1.03)	1961	0.99 (0.93, 1.05)	1.01 (0.95, 1.08)
Tertile 3	1933	0.96 (0.90, 1.02)	1.00 (0.93, 1.07)	2023	1.02 (0.96, 1.08)	1.05 (0.98, 1.12)

Note: HR, hazard ratio; 95% CI, 95% confidence interval. Fully adjusted models included age, marital status, country of birth, education level, area-level socioeconomic status, and smoking status.
[a] Sample size differs due to missing data for natural space area.
* $p < .05$.

Table 5
Hazard ratios and 95% confidence intervals for distance to nearest waterbody and all-cause mortality in the Health In Men Study (n = 9218 with 5889 deaths).

Distance to nearest waterbody	Deaths n	Age adjusted HR (95% CI)	Fully adjusted HR (95% CI)
Quartile 1	1447	Reference	Reference
Quartile 2	1502	1.09 (1.01, 1.17)*	1.10 (1.02, 1.18)*
Quartile 3	1477	1.05 (0.97, 1.12)	1.06 (0.98, 1.14)
Quartile 4	1462	1.02 (0.95, 1.09)	0.99 (0.92, 1.07)

Note: HR, hazard ratio; 95% CI, 95% confidence interval. Fully adjusted models included age, marital status, country of birth, education level, area-level socioeconomic status, and smoking status.
* $p < .05$.

ischemic heart disease, stroke, and non-malignant respiratory disease-related mortality (Villeneuve et al., 2012). Another Canadian study also found that higher levels of residential greenness were related to reduced mortality rates (Crouse et al., 2017). A Swiss study reported lower mortality rates related to greenness assessed with the NDVI, and associations were stronger for women than for men. Similar results were found for green spaces identified with land use maps (Vienneau et al., 2017). Our study focused on elderly men living in Perth, and may not be directly comparable to studies from North America and Europe that focused on other population groups with both men and woman across a range of ages. Our older male population was at considerable risk for mortality, and competing risks might explain the lack of an association between natural outdoor environments and mortality. A small area study undertaken in Spain could not establish a consistent association between NDVI surrounding greenness and mortality. In that study, greenness was related to higher mortality, but in areas of lower

Table 6
Hazard ratios and 95% confidence intervals for number and size of waterbodies and all-cause mortality in the Health In Men Study (n = 9218 with 5889 deaths).

Waterbodies	Deaths n	Age adjusted HR (95% CI)	Fully adjusted HR (95% CI)
Number (500 m buffer)			
0	3595	Reference	Reference
1	1593	1.01 (0.95, 1.07)	1.02 (0.96, 1.09)
≥ 2	704	1.02 (0.94, 1.11)	1.00 (0.92, 1.09)
Number (1000 m buffer)			
0	1215	Reference	Reference
1	1648	0.99 (0.92, 1.06)	1.04 (0.97, 1.13)
≥ 2	3029	1.04 (0.97, 1.11)	1.07 (1.00, 1.15)*
Size (500 m buffer)			
Tertile 1	3595	Reference	Reference
Tertile 2	342	1.19 (1.06, 1.33)*	1.16 (1.04, 1.30)*
Tertile 3	1955	0.99 (0.94, 1.05)	0.99 (0.94, 1.05)
Size (1000 m buffer)			
Tertile 1	1956	Reference	Reference
Tertile 2	2007	1.04 (0.97, 1.10)	1.05 (0.99, 1.12)
Tertile 3	1929	0.96 (0.91, 1.03)	1.02 (0.96, 1.09)

Note: HR, hazard ratio; 95% CI, 95% confidence interval. Fully adjusted models included age, marital status, country of birth, education level, area-level socioeconomic status, and smoking status.
* $p < .05$.

SES, greenness was associated with lower mortality (de Keijzer et al., 2016). We found no indication for effect modification by area SES. Previous studies that found an association with mortality reported average NDVI values ranging between 0.50 and 0.59, and are much higher than the average value in our study. Our and one other study showed that the Perth region has however high NOE availability and this might not have been captured well by the NDVI (Astell-Burt et al., 2014c). Although previous research from Australia (including Perth) reported health benefits of greenness (Astell-Burt et al., 2014a, 2014b; Pereira et al., 2012), no previous study assessed associations with mortality, making it difficult to compare our results to studies from the same region.

Evidence for a beneficial effect of blue spaces is less clear, because of a limited number of studies and mixed results (Gascon et al., 2016, 2017). The relationship between distance to waterbodies and mortality has been assessed by one previous study in 30 Canadian cities. Similar to our results, they found reduced mortality risks in those living within 250 m of waterbodies compared to living further away (Crouse et al., 2018). Related to that, two studies have reported a lower mortality risk related to cold temperatures (Madrigano et al., 2013) or heat (Burkart et al., 2015) for those living close to waterbodies compared with those living further away. Our results are, however, mixed. The beneficial effect of closer residential proximity to waterbodies may indicate that especially close access to water is beneficial to health, as it may stimulate visits to water, while this may not be the case for the number and size of waterbodies in an area. Our findings suggest a potential protective association between waterbodies and mortality, but this association is complex and might not be linear. These could also be chance findings and should be investigated in future studies. Further studies should also focus on how people interact with waterbodies to understand the potential beneficial effect of waterbodies and the mechanisms.

This study has a number of limitations. Our results are based on an older population of men residing in Perth, Western Australia and extrapolation to younger or female populations may not be appropriate. Although we studied time-varying residential surrounding greenness, we did not do this for parks, natural spaces and waterbodies because data was not available. Waterbodies may have remained stable over time, but this is less clear for parks and natural areas and future studies should consider time-varying access to these spaces. Participants that relocated during the study period were excluded because of lacking information on the relocation date. Studying relocation of residence introduces more variation in NOE exposure and could be useful in identifying causal effects of NOE on mortality in future studies. We did not evaluate the perceived access, use or quality of green and blue spaces and the association with mortality. Some mortality cases may have been missed when men died outside Western Australia. This is however estimated to only happen in a few cases (< 1%) (Norman et al., 2009). Cases of stroke- and respiratory disease-related mortality were in some instances low, and results should therefore be interpreted with caution. Finally, multiple testing may have resulted in chance findings (e.g. results for waterbodies). Nonetheless, this study also has a number of strengths. The Health In Men Study is a large, longitudinal cohort that is representative in terms of mortality risks of the general population of older men in Australia (McCaul et al., 2016). We studied not solely residential surrounding greenness, assessed with the NDVI, as done in many of the previous studies (Gascon et al., 2016; James et al., 2016; Nieuwenhuijsen et al., 2017). We also assessed the number and total area of parks and natural spaces within circular and road network buffers. Furthermore, we also investigated associations between waterbodies and mortality for which evidence is scarce.

5. Conclusions

In this longitudinal study of older men residing in Perth, we observed evidence suggestive of an association between access to natural spaces and decreased mortality. Associations between surrounding greenness and mortality seemed to be confounded by level of education, and associations with waterbodies were complex and need to be studied further.

Declaration of competing financial interests

The authors declare they have no actual or potential competing financial interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2019.01.075.

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